Trends in Anaesthesia and Critical Care 5 (2015) 28–35

Contents lists available at ScienceDirect

Trends in Anaesthesia and Critical Care

journal homepage: www.elsevier.com/locate/tacc

REVIEW

Preoperative assessment of the airway

Lauren C. Berkow [a,*], Promise Ariyo [b,1]

[a] Anesthesia and Critical Care Medicine, Otolaryngology, Head and Neck Surgery, Johns Hopkins School of Medicine, 600 North Wolfe Street, Phipps 404, Baltimore, MD 21287, USA
[b] Department of Anesthesiology and Critical Care Medicine, Johns Hopkins School of Medicine, 600 North Wolfe Street/Meyer 291, Baltimore, MD 21287, USA

Keywords:
Airway
Assessment tools
Multidisciplinary

SUMMARY

Failure to secure a patient's airway can cause severe and long-lasting consequences, including death. Indeed, failed airway management is a leading cause of legal claims in the field of anesthesiology. Anticipating and preparing for difficulty in airway management is crucial to avoiding airway catastrophes. Many of the traditional methods for predicting a difficult airway have low sensitivity and specificity, but prediction models and adjuncts to traditional methods of airway evaluation are being researched extensively. This article reviews airway assessment approaches, including the use of newer airway assessment models and imaging, and emphasizes the need for involvement of multiple disciplines to improve airway safety.

1. Introduction

The definition of a difficult airway varies greatly in the literature. The American Society of Anesthesiology's (ASA) Difficult Airway Guidelines define a difficult airway as one in which "a conventionally trained anesthesiologist experiences difficulty with face-mask ventilation of the upper airway, difficulty with tracheal intubation, or both".[1] Failed airway management can lead to rapid deterioration of oxygenation and ventilation and devastating consequences such as brain injury and death. The ASA Closed Claims database revealed that airway events account for 34% of all claims and that difficult intubation has been the most common damaging event in anesthesia claims since the 1990s.[2,3] Adequate preoperative airway planning, including specific techniques and equipment tailored to each specific patient, can play an important role in decreasing the risks associated with difficult airway management. A thorough review of the patient's medical history, comorbid conditions, and prior anesthetics is imperative for creating an airway-management plan. Specific airway assessment tools, especially when used in combination, can help in predicting difficult airway anatomy. In addition, especially in non-emergent situations, the use of imaging studies such as endoscopy and bedside ultrasound may improve the efficacy of existing prediction tools.

2. Predictors of difficult airway

2.1. Bedside airway assessment

When possible, anesthesia providers should perform a targeted history and physical examination of patients preoperatively. Anesthesia records should be reviewed, prior difficult airway should be noted as a risk factor,[4] and, if available, techniques used for previous airway management should be reviewed. Close attention should be paid to medical diagnoses, including laryngeal and mediastinal pathologies, as well as other diagnoses that have been associated with the difficult airway (Table 1).[5] In addition, several specific tests have been recommended to help predict difficult intubation (Table 2).

2.1.1. Overall appearance

The patient should then be assessed for physical signs of difficult mask ventilation and intubation. The assessment should begin with a look at the patient's general appearance. Any abnormal head and neck appearance, including masses, evidence of trauma such as lacerations, fractures and bleeding, or presence of a cervical collar should be noted and may alert the provider to possible difficulty.

* Corresponding author. Tel.: +1 (410) 955 7461; fax: +1 (410) 614 7903.
E-mail addresses: Lberkow1@jhmi.edu (L.C. Berkow), Pariyo1@jhmi.edu (P. Ariyo).
[1] Tel.: +1 410 955 9080; fax: +1 410 955 8978.

http://dx.doi.org/10.1016/j.tacc.2014.11.003
2210-8440/

Table 1
Disease states associated with difficult airway management.

Congenital	Acquired
Pierre–Robin syndrome	Morbid obesity
Treacher–Collins syndrome	Acromegaly
Goldenhar's syndrome	Infections involving the airway (Ludwig's Angina)
Mucopolysaccharidoses	Rheumatoid arthritis
Achondroplasia	Ankylosing spondylitis
Micrognathia	Tumors involving the airway
Down's syndrome	Trauma (airway, cervical spine)

Table 2
Predictors of difficult intubation.

Risk factor	References
Mallampati class	Tse,[16] Arne,[4] Naguib,[8] Iohom,[17] El-Ganzouri,[12] Langeron[15]
Head and neck movement	Tse,[16] Wilson,[7] Arne[4]
Mouth opening	Wilson,[7] Karkouti,[18] Langeron[15]
Thyromental distance	Tse,[16] Arne,[4] Naguib,[8] Iohom,[17] Langeron[15]
Sternomental distance	Iohom[17]
Upper lip bite test	Khan[19]
Prominent "buck" teeth	Wilson,[7] Naguib[8]
Inter-incisor distance	Arne[4]
Mandible luxation	Arne[4]

2.1.2. Mouth opening

The extent of mouth opening can be used to estimate ease of access to the larynx as well as mobility of the temporomandibular joint. A mouth opening of ≤4 cm has been identified as a risk factor for difficult intubation.[6] Examination of the mouth also allows for assessment of dentition. Dentures or loose teeth may be at risk for dislodgement during intubation. Prominent teeth may make placement of laryngoscope blades for direct laryngoscopy more challenging.[7,8]

2.1.3. Mallampati class

Subsequently, the size of the tongue relative to the pharyngeal space should be examined. This exam focuses on both mouth opening and the visibility of the pharyngeal space.[9] In his first description of the exam, Dr. Mallampati designated three classes for visualization of the uvula, tonsillar pillars, and palate. Samsoon and Young added a fourth class and linked higher Mallampati scores (III and IV) to higher (more difficult) Cormack–Lehane grades of laryngoscopy and difficult intubation (Fig. 1).[9,10] The four classes as they are now used are as follows:

Class I: Soft palate, uvula, fauces, and tonsillar pillars are visible.
Class II: Soft palate, uvula, and fauces are visible.
Class III: Soft palate and base of uvula are visible.
Class IV: Hard palate is visible.

A meta-analysis of the predictability of the Mallampati tests shows a good discriminatory power of the modified Mallampati score for difficult direct laryngoscopy (ROC 0.89 ± 0.05) and intubation (0.83 ± 0.03) but poor power for predicting difficult ventilation.[11]

2.1.4. Thyromental distance

Thyromental distance is the distance between the chin and the thyroid cartilage (measured in finger breadths or cm). This exam can be used to assess mandibular space and compliance and to predict the ease of tongue displacement during direct laryngoscopy. Patients with micrognathia (abnormally small mandible) or retrognathia (abnormally posterior mandible relative to other facial structures) will be expected to have short thyromental distances. Measurements less than 6 cm, especially coupled with higher Mallampati classes, have been associated with higher odds of difficult intubation.[12]

2.1.5. Neck range of motion

Good neck mobility with normal flexion and extension allows the anesthesia provider to manipulate the neck and enhance view on direct laryngoscopy. The extent of neck mobility, evidence of prior neck surgery, and pain and/or neurologic symptoms upon movement should be assessed. A retrospective review of >14,000 patients identified decreased cervical spine motion as an independent risk factor for difficult mask ventilation, direct laryngoscopy, and intubation.[13]

2.1.6. Combining prediction assessments

These physical exam findings and a myriad of others have poor predictive values when used alone. A meta-analysis published by Shiga et al.[14] confirmed that individual findings lack good discriminatory power but suggested that prediction is improved when findings are used in combination. Efforts have been made to develop prediction tools that use different combinations of the airway exam. Wilson et al.[7] developed a risk score using five risk factors (weight, head and neck movement, jaw movement, receding mandible, buck teeth) that had reasonable sensitivity but also high false-positive values. El-Ganzouri et al.[12] studied over 10,000 patients and identified seven risk factors for difficult intubation (mouth opening, thyromental distance, Mallampati class, neck movement, inability to extend the lower jaw, body weight,

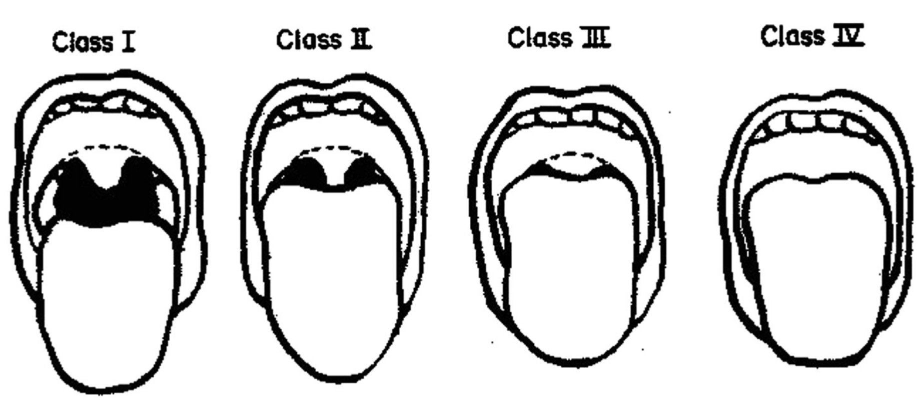

Fig. 1. Mallampati classes.

and positive history of difficult intubation). A multivariate analysis model of different risk factors was used to form predictive risk index scores that had better accuracy than the Mallampati scores alone for predicting difficult intubation scenarios. Langeron et al.[15] developed a comprehensive, computer-based prediction model in adult patients using variables that included Mallampati class, mouth opening, thyromental distance, body mass index, and presence of a receding mandible. With this computer model, they were able to use combinations of bedside airway assessment values, taking into account the complex interactions between them, to reasonably predict patients with low, intermediate, and high risk for intubation. Their model had a reasonable prediction of airway risk (ROC 0.86, 95% CI: 0.84–0.91, $p < 0.001$) and accuracy that was superior to that of other, more simplified scoring systems.

2.2. Predictors of difficult mask ventilation

Mask ventilation is arguably the most important skill of an anesthesia provider, but the ability to ventilate an anesthetized patient can be very difficult, even for the most experienced anesthesiologist. Difficult facemask ventilation is described as the inability to provide adequate ventilation because of one or more of the following problems: inadequate mask seal, excessive gas leak, or excessive resistance to the ingress or egress of gas.[20] A large prospective study by Langeron et al.[21] identified five risk factors that are predictive of difficulty with mask ventilation. The presence of at least two of the following factors—history of snoring, age (greater than 50, BMI $\geq$26), beard, and edentulous state—predicted difficult mask ventilation with a 72% sensitivity and 73% specificity. Other suggested anatomical risk factors for difficult mask ventilation include Mallampati class III or IV, limited mandibular protrusion, male gender, and the presence of an airway mass (Table 3).[22]

Table 3
Predictors of difficult mask ventilation.

Risk factor	References
Increased BMI	Langeron,[21] Yildiz,[23] Kheterpal[24]
History of snoring/sleep apnea	Langeron,[21] Kheterpal,[24]
Lack of teeth	Langeron[21]
Age greater than 55 years	Langeron,[21] Yildiz,[23] Kheterpal[24]
Mallampati III or IV	Yildiz,[23] Kheterpal[24]
Limited mandibular protrusion test	Kheterpal[24]
Male gender	Yildiz[23]
Airway masses/tumors	Moorthy[25]

BMI = body mass index.

3. Preoperative airway imaging

3.1. Perioperative endoscopic airway evaluation

Preoperative endoscopic airway evaluation (PEAE) has been described recently for assessing the airway of patients with suspected or known airway pathology. The aim is to determine the extent to which airway lesions, which are not easily identified on routine airway examination, will influence the strategy for airway management. In a cohort of 138 patients presenting for a variety of airway procedures, the use of PEAE as an adjunctive airway assessment caused anesthesiologists to change their airway strategy in 26% of cases to one that was different from the strategy suggested by airway assessment alone.[26]

3.2. Airway ultrasound

The role of ultrasonography has greatly expanded over the years. Ultrasonography is now being used for airway assessment and for confirmation of endotracheal tube placement. It is a quick and noninvasive tool. Multiple structures, including the tongue, oropharynx, hypopharynx, hyoid bone, and epiglottis, are well visualized on ultrasound, even if they are not identifiable by palpation. The larynx especially, because of its superficial structure, is better visualized on ultrasound than on computed tomography or magnetic resonance images, and the hypoechoic vocal cords can be seen outlined by the vocal ligaments.[27] (Fig. 2) Preoperative ultrasound can be used to identify airway pathology, landmarks for the performance of airway blocks, and the location of the cricothyroid membrane prior to airway management in patients with suspected airway difficulty.[28]

In a pilot study of adult patients undergoing elective surgery, preoperative ultrasonography measurements of anterior neck tissue at the level of the thyrohyoid membrane and hyoid bone were higher in patients with difficult airway than in those without difficult airway. Surprisingly, this measurement did not correlate with clinical predictive tools, suggesting that anterior neck measurements can help clinicians to identify patients with difficult airway anatomy when traditional clinical assessments are inadequate.[29]

Results from another small study of obese patients that compared ultrasonographic measurements of hyomental distance with the head in neutral versus hyperextended positions suggested that hyomental distance ratios of <1.1 were more predictive of a difficult airway than those >1.1.[30] Ezri et al.[31] was able to successfully predict difficult laryngoscopy by using pretracheal soft tissue measurements in obese patients, although other studies have not been able to replicate these predictive results.[32] Ezri found that the distance from the skin to the trachea, measured at the level of the vocal cords, was greater in obese patients with difficult laryngoscopy. Although more research is needed, some of the initial studies show promising results for the use of ultrasonography in the diagnosis and planning of a difficult airway.

3.3. Other imaging modalities

Diagnostic imaging, especially of the head, neck, or thorax, may provide valuable information about a patient's airway anatomy and potential pathologies. Cervical spine X-ray films may reveal cervical spine fractures, significant spondylosis, or inflammatory arthropathies that can potentially make routine intubation techniques more challenging.[33,34] A CT scan or MRI of the neck can reveal pathologies such as thyroid masses, vascular rings, congenital stenosis, or tracheomalacia that may distort the normal tracheal anatomy and affect intubation strategies (Fig 5).

4. Special patient populations

4.1. The obese patient

Obesity is a global epidemic that deserves special attention. Nearly 35% of American adults are considered obese,[35] which is defined by the World Health Organization as a BMI >30 kg/m^2.[36] Obese patients present with a unique set of challenges for perioperative care. They have low residual volumes and decreased functional residual capacity; therefore they have low respiratory reserves to meet the demands of their increased minute ventilation. Some evidence suggests that obese patients have an increased incidence of difficult airway management, although this idea is highly debated. Langeron et al.[21] found high BMI (>26 kg/m^2) and obstructive sleep apnea (OSA), which is common in obese patients, to be risk factors of difficult mask ventilation. In addition, 30% of those patients were also difficult to intubate.

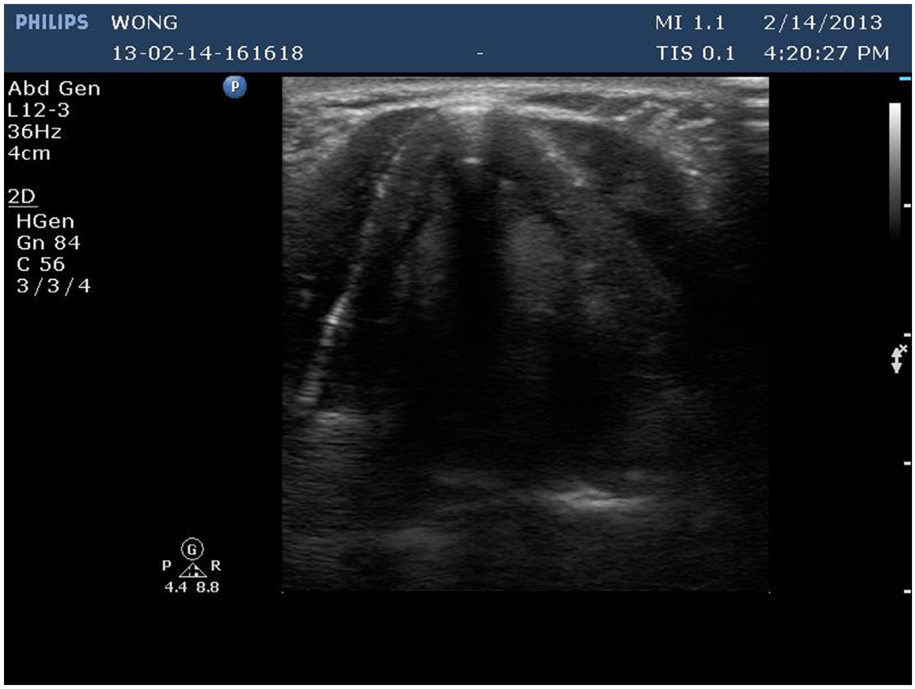

Fig. 2. Vocal cords identified by ultrasound, courtesy of David Wong, MD, University of Toronto.

On the validated Intubation Difficulty Scale (IDS), difficulty with intubation is defined as a score ≥ 5. Juvin et al.[37] found that the IDS score was statistically significantly higher in obese patients (BMI ≥ 35 kg/m^2) than in lean patients (BMI < 30 kg/m^2)—15% vs. 2.2%. Similar findings were reported by Gonzalez et al.,[38] who showed that BMI ≥30 kg/m^2 and large neck circumference were independently associated with difficult intubation. A meta-analysis by Shiga et al.[14] revealed that the incidence of difficult intubation was 15.8% in obese patients (BMI ≥ 30 kg m^2) but only 5.8% in the non-obese population.

However, other studies suggest that obesity is not a risk factor for difficult airway management. Neligan et al.[39] studied 180 morbidly obese patients (BMI ≥ 40 kg/m^2) undergoing elective surgery and did not find an association between difficult airway and BMI, neck circumference, or OSA. Brodsky et al.[40] looked at 100 morbidly obese patients (BMI ≥ 40 kg/m^2) and also found no association between BMI and difficulty with intubation.

Although the literature is equivocal, the presence of obesity along with other findings, such as higher Mallampati scores and OSA, should raise concern for potential difficult airway. In particular, patients with central obesity (higher fat distribution around abdominal and visceral organs) are at higher risk for OSA, cardiovascular disease, and overall mortality than are patients with peripheral obesity.[41–43] Patients can be screened for OSA with the STOP BANG questionnaire (Fig 3), a validated tool that has high sensitivity and specificity. Chung et al.[44] reported that a score of ≥3 on the STOP BANG questionnaire can predict OSA with sensitivities of 93% and 100% for moderate and severe OSA, respectively.

Snoring: Do you snore loudly (loud enough to be heard through closed doors)?

Tired: Do you often feel tired, fatigued, or sleepy during daytime?

Observed: Has anyone observed you stop breathing during your sleep?

Blood **P**ressure: Do you have or are you being treated for high blood pressure?

BMI: Body Mass Index > than 35 kg m^{-2}?

Age: Age over 50 years old?

Neck circumference: Neck circumference >40 cm?

Gender: Male?

≥ 3 factors is associated with high likelihood for obstructive sleep apnea

Fig. 3. STOP BANG assessment for obstructive sleep apnea.

Variable	Score
Mallampati class III or IV	5
Obstructive sleep apnea syndrome	2
Reduced mobility of the cervical spine	1
Limited mouth opening (<3 cm)	1
Presence of coma (Glasgow coma scale < 8)	1
Severe hypoxia (<80% oxygen saturation)	1
Non-anesthesiologist operator	1

Fig. 4. MACOCHA scores for predicting difficult airway in critically ill patients. Scores of $\geq$3 predicted difficult airway with good sensitivity and specificity.

This patient cohort may benefit from additional preparation before airway management, such as appropriate positioning and additional time for pre-oxygenation. Several studies have suggested that a ramped position (head and shoulders are elevated, bringing the external auditory meatus to the same level as the sternum) will facilitate intubation (Fig. 6) and improve pre-oxygenation.[45–47]

4.2. The pregnant patient

Pregnant women are at eight times higher risk of having a difficult airway than are patients in the average surgical population.[10] Difficult intubation and esophageal intubation have been reported as leading causes of anesthesia-related obstetric complications.[48,49] Pregnant patients present many special challenges with regard to airway management. They are considered to have "full stomachs," and most general anesthetics in obstetrics are emergent in nature. In addition, pregnant women undergo anatomical and physiologic changes that make the airway more challenging. Increased airway edema, larger breasts, increased oxygen consumption, and decreased functional residual capacity all present challenges to airway management.[50–52]

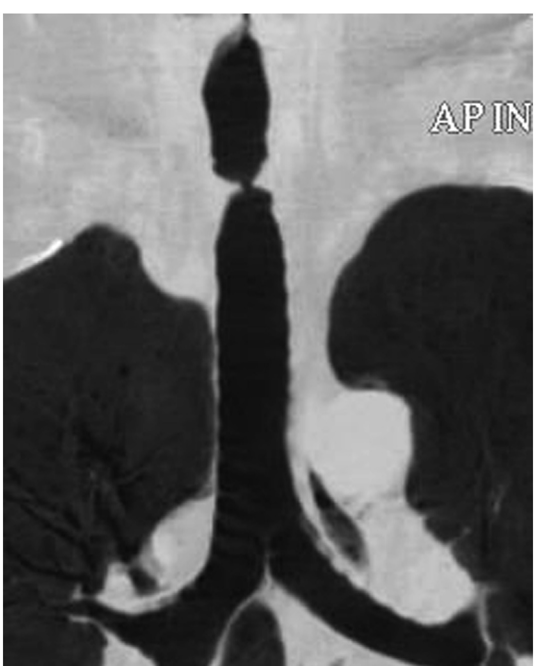

Fig. 5. CT scan external rendering showing tracheal narrowing. Courtesy of David Feller–Kopman, MD.

Because more than 30% of infants in the United States are delivered via cesarean section,[53] anesthesiologists should be well aware of the peculiarities associated with the airway of pregnant women. The Mallampati class has been described to have good predictability during pregnancy. A study of 242 patients with photographic recordings of their Mallampati scores at 26 weeks of pregnancy showed an increase of 34% in the number of class IV ratings.[54] Anesthesia providers should evaluate laboring pregnant women for regional anesthesia and airway difficulty early in the delivery period to decrease the need for general anesthesia and risks of airway instrumentation if urgent cesarean section is needed. Adequate and functional equipment should be ready in the event of difficulty, with multiple back-up airway device options available as alternatives. Additional providers should be available whenever possible to provide assistance for rapidly and safely securing the airway. Careful positioning of the patient into a sniff position improves alignment of the oral, pharyngeal, and laryngeal axes and thus visualization of the airway. Some studies suggest that obese pregnant patients are likely to benefit from a ramped position.[45,55]

4.3. The trauma patient

Airway management can be extremely challenging in the trauma patient. The emergent nature of most surgical procedures, the presence of a full stomach, and the possibility of active oropharyngeal bleeding put these patients at high risk for intubation. Depressed level of consciousness, intoxication, or a combative state may make assessment of airway anatomy via traditional means quite difficult. In addition, many trauma patients are assumed to have unstable cervical spines prior to radiologic assessment and present in a cervical collar. This uncertainty about

Fig. 6. Ramped position for intubation in which the external auditory meatus is aligned with the sternum (*Courtesy of airpal*).

spinal mobility limits both airway assessment and optimization of patient position for laryngoscopy and intubation.

The LEMON pneumonic (Table 4) is recommended as a tool to assess trauma patients. It is quick and simple to use, thereby enabling rapid assessment of patients for whom attaining a definitive airway is urgent and imperative. A study by Reed et al.[56] demonstrated that this tool can be used successfully to stratify patients at high risk for difficult intubation in the emergency department. Patients with a LEMON score of 3 or higher were found to have a higher incidence of difficult intubation. In addition, the presence of large incisors, a reduced inter-incisor distance, and a reduced thyroid-to-floor-of-mouth distance were correlated ($p < 0.005$) with difficulty.

4.4. The critically ill patient

The incidence of difficult intubation is higher in patients in the Intensive Care Unit (ICU) than in patients in other settings. Some studies have reported rates as high as 23% among ICU patients, compared to about 1–4% in the general surgical patient population.[57–59] Because the underlying physiologic reserve is poor, airway events are poorly tolerated by these patients and are associated with very high complication rates.[60,61] The Fourth National Audit Project (NAP4) published by the Difficult Airway Society found a significantly higher incidence of airway-related complications in ICU patients. The NAP4 study also found that inadequate equipment, lack of capnography, and delayed recognition of high-risk patients was associated with airway-related adverse events.[62,63] Unfortunately, many scenarios in the ICU preclude a good airway assessment. Patients often have depressed mental status and therefore are not able to follow commands for an airway examination. In addition, the need to secure the airway is often urgent. De Jong et al.[61] identified a scoring system known as the MACOCHA score from a prospective multicenter study of 1000 consecutive intubations in 42 ICUs. MACOCHA scores (Mallampati Score III or IV, Apnea, Cervical spine limitation, Opening mouth <3 cm, Hypoxia, Anesthesiology non-trained) are seven simple variables that discriminate well between difficult and non-difficult intubations in the ICU (Fig. 4). In results from the initial study cohort, the area under the curve (AUC) was 0.89, and the 95% confidence interval was 0.85–0.94. When applied to a validation cohort, AUC was 0.86, 95% confidence interval was 0.76–0.96, sensitivity was 73%, and specificity was 89%. The negative predictive value was 98%, but the positive predictive value was lower at 36%, which the authors attributed to the low incidence of difficult intubation (8%) in the validation cohort. In addition to the patient factors, this tool uses factors related to severity of illness, including degree of hypoxemia, which decreases time to oxygen desaturation, and the presence of coma, which can result in increased secretions and poor visualization. Emphasis should be on optimizing the intubating environment as much as possible—capnography, alternate airway equipment, and additional provider support should be immediately available.

Table 4
LEMON airway assessment.

Assessment	Description
Look	Examine for gross abnormalities or lesions, trauma, large tongue
Evaluate 3–3–2 rule	Inter-incisor distance (<3 finger breaths) Hyoid-mental distance (<3 finger breaths) Thyroid-floor-of-the-mouth distance (<2 finger breaths)
Mouth opening	Assess Mallampati class (>3)
Obstruction	Conditions that can cause obstructions such as epiglottitis, peritonsillar abscesses
Neck mobility	Presence of hard collar, inability to extend neck

5. A systematic approach to airway management

The involvement of multidisciplinary teams can lead to earlier identification of high-risk patients and allow for advance planning of airway management, potentially reducing complications associated with difficult airways. Surgeons, endoscopists, intensivists, and other proceduralists who have early contact with patients should be familiar with the predictors of a difficult airway. Early identification of such patients will aid in planning for appropriate airway equipment and strategies. Many hospitals have preoperative evaluation clinics to which such patients can be referred for airway and other anesthesia-related consultations. In addition, wider use of national difficult airway registries, such as the MedicAlert Foundation (www.medicalert.org), can help track patients with known history of difficult airway management and alert future airway providers.[64] Routine use of checklists, such as the WHO safe surgery checklist, can also help to identify patients in the immediate perioperative period and decrease perioperative complications.[65] Early identification of patients at risk also provides for the opportunity to discuss and prepare the patient for difficult airway management.

6. Summary

The ASA recently updated the Practice Guidelines for Management of the Difficult Airway. The new guidelines continue to emphasize the need for directed history and physical exam. Adjunctive diagnostic imaging is recommended in specific patient populations as guided by initial history and physical examination findings.[20] Numerous difficult-airway prediction tools exist, but providers must appreciate their limitations in predicting this rare outcome.[66,67] Given these limitations, adequate preparation with functional equipment and alternative plans must accompany airway assessment for individual patients. Additionally, because of the unusual factors associated with these cases, airway scenarios outside the operating rooms must be given special attention. Perioperative providers from multiple disciplines should be involved in early identification and referral of patients with difficult airway history or signs.

Conflicts of interest

The authors have no conflicts of interest.

References

1. Practice guidelines for management of the difficult airway. A report by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway. *Anesthesiology* 1993;**78**(3):597–602.
2. Metzner J, Posner KL, Lam MS, Domino KB. Closed claims' analysis. *Best Pract Res Clin Anaesthesiol* 2011;**25**(2):263–76.
3. Caplan RA, Posner KL, Ward RJ, Cheney FW. Adverse respiratory events in anesthesia: a closed claims analysis. *Anesthesiology* 1990;**72**(5):828–33.
4. Arné J, Descoins P, Fusciardi J, Ingrand P, Ferrier B, Boudigues D, et al. Preoperative assessment for difficult intubation in general and ENT surgery: predictive value of a clinical multivariate risk index. *Br J Anaesth* 1998;**80**(2):140–6.
5. Rosenblatt WH, Sukhupragarn W. Airway management. In: Barash PG, et al., editors. *Clinical anesthesia*. Philadelphia: Wolters Kluwer/Lippincott Williams and Wilkins; 2009. p. 751–92.
6. Rose DK, Cohen MM. The airway: problems and predictions in 18,500 patients. *Can J Anaesth* 1994;**41**(5 Pt 1):372–83.
7. Wilson ME, Spiegelhalter D, Robertson JA, Lesser P. Predicting difficult intubation. *Br J Anaesth* 1988;**61**(2):211–6.
8. Naguib M, Malabarey T, AlSatli RA, Al Damegh S, Samarkandi AH. Predictive models for difficult laryngoscopy and intubation. A clinical, radiologic and three-dimensional computer imaging study. *Can J Anaesth* 1999;**46**(8):748–59.
9. Mallampati SR, Gatt SP, Gugino LD, Desai SP, Waraksa B, Freiberger D, et al. A clinical sign to predict difficult tracheal intubation: a prospective study. *Can Anaesth Soc J* 1985;**32**(4):429–34.
10. Samsoon GL, Young JR. Difficult tracheal intubation: a retrospective study. *Anaesthesia* 1987;**42**(5):487–90.
11. Lee A, Fan LT, Gin T, Karmakar MK, Ngan Kee WD. A systematic review (meta-analysis) of the accuracy of the Mallampati tests to predict the difficult airway. *Anesth Analg* 2006;**102**(6):1867–78.
12. el-Ganzouri AR, McCarthy RJ, Tuman KJ, Tanck EN, Ivankovich AD. Preoperative airway assessment: predictive value of a multivariate risk index. *Anesth Analg* 1996;**82**(6):1197–204.
13. Mashour GA, Stallmer ML, Kheterpal S, Shanks A. Predictors of difficult intubation in patients with cervical spine limitations. *J Neurosurg Anesthesiol* 2008;**20**(2):110–5.
14. Shiga T, Wajima Z, Inoue T, Sakamoto A. Predicting difficult intubation in apparently normal patients: a meta-analysis of bedside screening test performance. *Anesthesiology* 2005;**103**(2):429–37.
15. Langeron O, Cuvillon P, Ibanez-Esteve C, Lenfant F, Riou B, Le Manach Y. Prediction of difficult tracheal intubation: time for a paradigm change. *Anesthesiology* 2012;**117**(6):1223–33.
16. Tse JC, Rimm EB, Hussain A. Predicting difficult endotracheal intubation in surgical patients scheduled for general anesthesia: a prospective blind study. *Anesth Analg* 1995;**81**(2):254–8.
17. Iohom G, Ronayne M, Cunningham AJ. Prediction of difficult tracheal intubation. *Eur J Anaesthesiol* 2003;**20**(1):31–6.
18. Karkouti K, Rose DK, Wigglesworth D, Cohen MM. Predicting difficult intubation: a multivariable analysis. *Can J Anaesth* 2000;**47**(8):730–9.
19. Khan ZH, Kashfi A, Ebrahimkhani E. A comparison of the upper lip bite test (a simple new technique) with modified Mallampati classification in predicting difficulty in endotracheal intubation: a prospective blinded study. *Anesth Analg* 2003;**96**(2):595–9. table of contents.
20. Apfelbaum JL, Hagberg CA, Caplan RA, Blitt CD, Connis RT, Nickinovich DG, et al. Practice guidelines for management of the difficult airway: an updated report by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway. *Anesthesiology* 2013;**118**(2):251–70.
21. Langeron O, Masso E, Huraux C, Guggiari M, Bianchi A, Coriat P, et al. Prediction of difficult mask ventilation. *Anesthesiology* 2000;**92**(5):1229–36.
22. El-Orbany M, Woehlck HJ. Difficult mask ventilation. *Anesth Analg* 2009;**109**(6):1870–80.
23. Yildiz TS, Solak M, Toker K. The incidence and risk factors of difficult mask ventilation. *J Anesth* 2005;**19**(1):7–11.
24. Kheterpal S, Han R, Tremper KK, Shanks A, Tait AR, O'Reilly M, et al. Incidence and predictors of difficult and impossible mask ventilation. *Anesthesiology* 2006;**105**(5):885–91.
25. Moorthy SS, Gupta S, Laurent B, Weisberger EC. Management of airway in patients with laryngeal tumors. *J Clin Anesth* 2005;**17**(8):604–9.
26. Rosenblatt W, Ianus AI, Sukhupragam W, Fickenscher A, Sasaki C. Preoperative endoscopic airway examination (PEAE) provides superior airway information and may reduce the use of unnecessary awake intubation. *Anesth Analg* 2011;**112**(3):602–7.
27. Kristensen MS, Teoh WH, Graumann O, Laursen CB. Ultrasonography for clinical decision-making and intervention in airway management: from the mouth to the lungs and pleurae. *Insights Imaging* 2014;**5**(2):253–79.
28. Teoh WH, Kristensen MS. Utility of ultrasound in airway management. *Trends Anesth Crit Care* 2014;**4**:84–90.
29. Adhikari S, Zeger W, Schmier C, Crum T, Craven A, Frrokaj I, et al. Pilot study to determine the utility of point-of-care ultrasound in the assessment of difficult laryngoscopy. *Acad Emerg Med* 2011;**18**(7):754–8.
30. Wojtczak JA. Submandibular sonography: assessment of hyomental distances and ratio, tongue size, and floor of the mouth musculature using portable sonography. *J Ultrasound Med* 2012;**31**(4):523–8.
31. Ezri T, Gewürtz G, Sessler DI, Medalion B, Szmuk P, Hagberg C, et al. Prediction of difficult laryngoscopy in obese patients by ultrasound quantification of anterior neck soft tissue. *Anaesthesia* 2003;**58**(11):1111–4.
32. Komatsu R, Sengupta P, Wadhwa A, Akça O, Sessler DI, Ezri T, et al. Ultrasound quantification of anterior soft tissue thickness fails to predict difficult laryngoscopy in obese patients. *Anaesth Intensive Care* 2007;**35**(1):32–7.
33. Bougaki M, Sawamura S, Matsushita F, Hanaoka K. Difficult intubation due to ossification of the anterior longitudinal ligament. *Anaesthesia* 2004;**59**(3):303–4.
34. Crosby ET, Lui A. The adult cervical spine: implications for airway management. *Can J Anaesth* 1990;**37**(1):77–93.
35. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of childhood and adult obesity in the United States, 2011-2012. *Jama* 2014;**311**(8):806–14.
36. World Health Organization. *Obesity and overweight fact sheet*. March 2013 [April 28, 2014]. Available from: who.int/mediacentre/factsheets/fs311/en/.
37. Juvin P, Lavaut E, Dupont H, Lefevre P, Demetriou M, Dumoulin JL, et al. Difficult tracheal intubation is more common in obese than in lean patients. *Anesth Analg* 2003;**97**(2):595–600. table of contents.
38. Gonzalez H, Minville V, Delanoue K, Mazerolles M, Concina D, Fourcade O. The importance of increased neck circumference to intubation difficulties in obese patients. *Anesth Analg* 2008;**106**(4):1132–6. table of contents.
39. Neligan PJ, Porter S, Max B, Malhotra G, Greenblatt EP, Ochroch EA. Obstructive sleep apnea is not a risk factor for difficult intubation in morbidly obese patients. *Anesth Analg* 2009;**109**(4):1182–6.
40. Brodsky JB, Lemmens HJ, Brock-Utne JG, Vierra M, Saidman LJ. Morbid obesity and tracheal intubation. *Anesth Analg* 2002;**94**(3):732–6. table of contents.
41. Isono S. Obstructive sleep apnea of obese adults: pathophysiology and perioperative airway management. *Anesthesiology* 2009;**110**(4):908–21.
42. Schafer H, Pauleit D, Sudhop T, Gouni-Berthold I, Ewig S, Berthold HK. Body fat distribution, serum leptin, and cardiovascular risk factors in men with obstructive sleep apnea. *Chest* 2002;**122**(3):829–39.
43. Larsson B, Svardsudd K, Welin L, Wilhelmsen L, Bjorntorp P, Tibblin G. Abdominal adipose tissue distribution, obesity, and risk of cardiovascular disease and death: 13 year follow up of participants in the study of men born in 1913. *Br Med J (Clin Res Ed)* 1984;**288**(6428):1401–4.
44. Chung F, Yegneswaran B, Liao P, Chung SA, Vairavanathan S, Islam S, et al. STOP questionnaire: a tool to screen patients for obstructive sleep apnea. *Anesthesiology* 2008;**108**(5):812–21.
45. Collins JS, Lemmens HJ, Brodsky JB, Brock-Utne JG, Levitan RM. Laryngoscopy and morbid obesity: a comparison of the "sniff" and "ramped" positions. *Obes Surg* 2004;**14**(9):1171–5.
46. Rao SL, Kunselman AR, Schuler HG, DesHarnais S. Laryngoscopy and tracheal intubation in the head-elevated position in obese patients: a randomized, controlled, equivalence trial. *Anesth Analg* 2008;**107**(6):1912–8.

47. Murphy C, Wong DT. Airway management and oxygenation in obese patients. *Can J Anaesth* 2013;**60**(9):929–45.
48. Hawkins JL. Anesthesia-related maternal mortality. *Clin Obstet Gynecol* 2003;**46**(3):679–87.
49. Chadwick HS, Posner K, Caplan RA, Ward RJ, Cheney FW. A comparison of obstetric and nonobstetric anesthesia malpractice claims. *Anesthesiology* 1991;**74**(2):242–9.
50. Munnur U, de Boisblanc B, Suresh MS. Airway problems in pregnancy. *Crit Care Med* 2005;**33**(10 Suppl.):S259–68.
51. Archer Jr GW, Marx GF. Arterial oxygen tension during apnoea in parturient women. *Br J Anaesth* 1974;**46**(5):358–60.
52. Kuczkowski KM, Reisner LS, Benumof JL. Airway problems and new solutions for the obstetric patient. *J Clin Anesth* 2003;**15**(7):552–63.
53. Hamilton BE, Martin JA, Ventura SJ. Births: preliminary data for 2012. *Natl Vital Stat Rep* 2013;**62**(3):1–20.
54. Pilkington S, Carli F, Dakin MJ, Romney M, De Witt KA, Doré CJ, et al. Increase in Mallampati score during pregnancy. *Br J Anaesth* 1995;**74**(6):638–42.
55. Dixon BJ, Dixon JB, Carden JR, Burn AJ, Schachter LM, Playfair JM, et al. Preoxygenation is more effective in the 25 degrees head-up position than in the supine position in severely obese patients: a randomized controlled study. *Anesthesiology* 2005;**102**(6):1110–5. discussion 5A.
56. Reed MJ, Dunn MJ, McKeown DW. Can an airway assessment score predict difficulty at intubation in the emergency department? *Emerg Med J* 2005;**22**(2):99–102.
57. Heuer JF, Barwing TA, Barwing J, Russo SG, Bleckmann E, Quintel M, et al. Incidence of difficult intubation in intensive care patients: analysis of contributing factors. *Anaesth Intensive Care* 2012;**40**(1):120–7.
58. Schwartz DE, Matthay MA, Cohen NH. Death and other complications of emergency airway management in critically ill adults. A prospective investigation of 297 tracheal intubations. *Anesthesiology* 1995;**82**(2):367–76.
59. Benumof JL. Management of the difficult adult airway. With special emphasis on awake tracheal intubation. *Anesthesiology* 1991;**75**(6):1087–110.
60. Griesdale DE, Bosma TL, Kurth T, Isac G, Chittock DR. Complications of endotracheal intubation in the critically ill. *Intensive Care Med* 2008;**34**(10):1835–42.
61. De Jong A, Molinari N, Terzi N, Mongardon N, Arnal JM, Guitton C, et al. Early identification of patients at risk for difficult intubation in the intensive care unit: development and validation of the MACOCHA score in a multicenter cohort study. *Am J Respir Crit Care Med* 2013;**187**(8):832–9.
62. Cook TM, MacDougall-Davis SR. Complications and failure of airway management. *Br J Anaesth* 2012;**109**(Suppl. 1):i68–85.
63. Woodall N, Frerk C, Cook TM. Can we make airway management (even) safer?–lessons from national audit. *Anaesthesia* 2011;**66**(Suppl. 2):27–33.
64. Mark LJ, Foley LA. Effective dissemination of critical information: the MedicAlert National Difficult Airway/Intubation Registry. In: Hagberg CA, editor. *Benumof's airway management*. 3rd ed. St Loius: Mosby; 2013.
65. Haynes AB, Weiser TG, Berry WR, Lipsitz SR, Breizat AH, Dellinger EP, et al. A surgical safety checklist to reduce morbidity and mortality in a global population. *N Engl J Med* 2009;**360**(5):491–9.
66. Yentis SM. Predicting difficult intubation–worthwhile exercise or pointless ritual? *Anaesthesia* 2002;**57**(2):105–9.
67. Ramachandran SK, Klock AP. Definition and incidence of the difficult airway. In: Benumof J, Hagberg CA, editors. *Benumof and Hagberg's airway management*. Philadelphia: Elsevier/Saunders; 2013. p. 209–21.